Shape-memory polymers

Shape-memory polymers are an emerging class of active polymers that have dual-shape capability. They can change their shape in a predefined way from shape A to shape B when exposed to an appropriate stimulus. While shape B is given by the initial processing step, shape A is determined by applying a process called programming. We review fundamental aspects of the molecular design of suitable polymer architectures, tailored programming and recovery processes, and the quantification of the shape-memory effect. Shape-memory research was initially founded on the thermally induced dual-shape effect. This concept has been extended to other stimuli by either indirect thermal actuation or direct actuation by addressing stimuli-sensitive groups on the molecular level. Finally, polymers are introduced that can be multifunctional. Besides their dual-shape capability, these active materials are biofunctional or biodegradable. Potential applications for such materials as active medical devices are highlighted.

General concept of shape-memory polymers

The shape-memory effect is not an intrinsic property, meaning that polymers do not display this effect by themselves. Shape memory results from a combination of polymer morphology and specific processing and can be understood as a polymer functionalization.

To display shape-memory functionality, the polymer network has to be temporarily fixed in a deformed state under environmental conditions relevant to the particular application. This requires the deformed chain segments, which are under external stress, to be reversibly prevented from recoiling, and is achieved by the introduction of reversible netpoints as the molecular switches. These additional netpoints can be formed by physical interactions or by covalent bonds. Physical cross-linking is obtained by vitrification or crystallization of domains related to T_{trans}. These switching domains can be formed either by the chain segments driving the entropic elastic behavior themselves or by side chains, whose aggregation is able temporarily to prevent recoiling of that chain's side chains or the side chain segments themselves. Reversible covalent cross-linking is obtained by attaching functional groups to the chain segments. Controlled by an external stimulus, these functional groups must be able to form covalent bonds reversibly by reaction with each other or suitable counterpart functional groups.